

The Interstellar Production of Biologically Important Organics

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One of the primary tasks of the Astrochemistry Laboratory at Ames Research Center is to use laboratory simulations to study the chemical processes that occur in dense interstellar clouds. Since new stars are formed in these clouds, their materials may be responsible for the delivery of organics to new habitable planets and may play important roles in the origin of life. These clouds are extremely cold (<50 kelvin), and most of the volatiles in these clouds are condensed onto dust grains as thin ice mantles. These ices are exposed to cosmic rays and ultraviolet (UV) photons that break chemical bonds and result in the production of complex molecules when the ices are warmed (as they would be when incorporated into a star-forming region). Using cryovacuum systems and UV lamps, this study simulates the conditions of these clouds and studies the resulting chemistry. Some of the areas of progress made in 1999 are described below. Figure 1 shows some of the types of molecules that may be formed in the interstellar medium. Laboratory simulations have already confirmed that many of these compounds are made under these conditions.

Polycyclic aromatic hydrocarbons (PAHs) are common in carbonaceous chondrites and interplanetary dust particles (IDPs), are abundant in space, and have been detected in interstellar ices. Results have shown that PAHs that are UV processed in H₂O ices undergo both oxidation and reduction reactions. The resulting species include aromatic ketones, alcohols, ethers, and H_n-PAHs (partially reduced PAHs). In addition, isotopic studies show that this process can enrich PAHs in deuterium, and may explain the D-enrichments seen in aromatics in meteorites. Recent studies on the UV processing of the PAH naphthalene in H₂O ice show that various naphthols and 1,4-naphthaquinone are formed. Since naphthaquinones are common in living systems, and since they perform fundamental roles in biochemistry (they are involved in electron transport), the extraterrestrial delivery of these compounds to the early Earth may be responsible for their presence in biochemistry.

Studies of the complex organics produced when 10 kelvin interstellar ice analogs are UV irradiated have continued. The residues remaining after the ices are warmed have been analyzed by high-performance liquid chromatography (HPLC) and by laser desorption mass spectrometry (in collaboration with Richard Zare and colleagues at Stanford University). This material contains a rich mixture of compounds with mass spectral profiles resembling those found in interplanetary dust particles (IDPs). Surface-tension measurements (made in collaboration with David Deamer of the University of California, Santa Cruz) show that an amphiphilic component is also present. When residues from the present study are dispersed in aqueous media, the organic material self-organizes into 10- to 40-micron-diameter droplets that fluoresce at 300 to 450 nanometers under UV excitation. These droplets have morphologies that are strikingly similar to those produced by extracts of the Murchison meteorite. The amphiphilic nature of these materials is responsible for the molecular self-assembly, and these compounds could have played a role in the formation of early membranous boundary structures required for the first forms of cellular life.

Together, these results suggest a link between organic material photochemically synthesized on the cold grains in dense, interstellar molecular clouds and compounds that may have contributed to the prebiotically important organic inventory of the primitive Earth.

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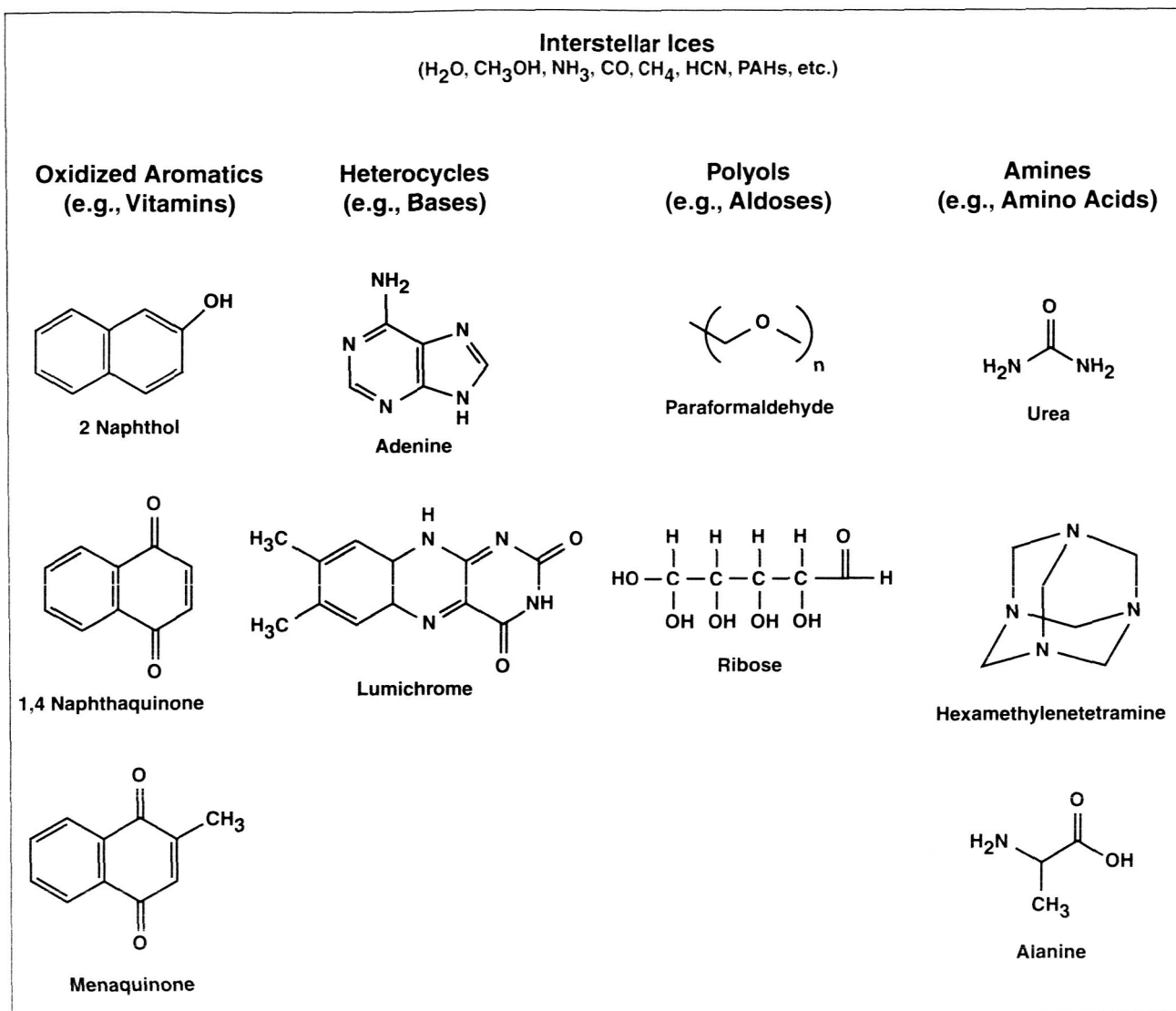


Fig. 1. Some of the classes of compounds that may be produced in low-temperature interstellar ices by UV photolysis. Many of these species have already been identified or tentatively identified in the present interstellar simulations (2-naphthol, 1,4-naphthaquinone, paraformaldehyde, urea, hexamethylenetetramine, and alanine).